**Program Objectives**

1. Monitor physical, chemical, and biological characteristics of mountain lakes in remote areas of three North Coast and Cascades Network parks to determine changes over time to individual lakes, as well as lakes park-wide and network-wide.
2. Determine the influence of independent variables such as annual precipitation, temperature, bedrock geology, or watershed characteristics, on network-wide trends for North Coast and Cascades Network mountain lakes.

Photo: Macroinvertebrate sampling in Thunder Lake, Ross Lake National Recreational Area, North Cascades National Park Complex. NPS/NOCA

# *Mountain Lakes*

TO THE EXHAUSTED MONITORING CREW, the mountain lake gleams like a mirage at the edge of the trees. They've hiked for days to gather samples from this hidden ecosystem that is ice-free only two months out of the year. Beneath the surface of this apparently pristine lake is an oasis of information about the impacts of environmental changes on a local and global level.

North Coast and Cascades Network (NCCN) mountain lakes are valued for their aesthetic beauty and their vital roles in ecosystems. They serve as inspiration for park visitors, links to neighboring terrestrial environments, critical breeding sites for amphibians and insects, and water sources and feeding grounds for wildlife. While these ecosystems and their hardy inhabitants are adapted to extreme conditions, mountain lakes are highly sensitive to change. This makes them excellent places to discover how environmental changes in climate, air pollution, exotic species, and visitor use might affect high elevation areas of the Pacific Northwest.

Mountain lakes are like "petri dishes in the sky," said Steven Fradkin, National Park Service (NPS) limnologist and Olympic National Park's principal investigator for mountain lakes. "These [lakes] represent discrete little ecosystems that are scattered around on mountainsides exposed to local and regional impacts." Mountain lakes occur at high elevations, receive most of their precipitation from snowfall, have small catchments, and are often located within closed basins: areas where most of the water entering a basin remains there. These characteristics make them particularly susceptible to atmospheric processes such as climate change and air pollution, whose impacts are subtle but profound when they do occur.

**By: Emily Linroth**

Scientists monitor mountain lakes in three of the NCCN parks: Mount Rainier National Park (Mount Rainier), North Cascades National Park Complex (North Cascades), and Olympic National Park (Olympic) as part of the Inventory and Monitoring Vital Signs program. Levels of human impact, whether urban or agricultural, vary between parks. Because of these impacts, parks may respond differently to some disturbances, such as atmospheric deposition of contaminants, while responding similarly to others, such as climate change.

The NCCN's mountain lakes are affected by both anthropogenic and natural disturbances. Rapid human population growth in the Pacific Northwest throughout the last century has most likely increased the magnitude of anthropogenic impacts and exacerbated effects of climate change and air pollution, two key concerns of the mountain lakes monitoring program.

Mount Rainier and North Cascades are influenced by local contaminants from agricultural areas in Eastern Washington and from industrialized regions of Puget Sound from Portland, Oregon to the south and British Columbia's Fraser Valley to the north. Olympic is impacted by local shipping traffic, but is primarily influenced by global background levels of contaminants, providing scientists a perspective on local versus global impacts.

Airborne contaminants can enter mountain lakes via air turbulence and precipitation, which can alter water quality and impact aquatic organisms. These contaminants include tiny particles of heavy metals, such as mercury, and pesticides. Contaminants deposited from the air may enter the food supply and biomagnify, producing compounding effects as they move up the food chain. More obvious impacts can include genetic mutations in fish and other organisms.

Many lakes such as those at North Cascades lack buffering capacity to neutralize the effects of added sulfur and nitrogen. These elements can fall as acid rain, altering a lake's acidity and impacting its inhabitants. In some Rocky Mountain lakes, entire species of algae have disappeared due to increasing nitrogen levels. Research indicates that the majority of sulfur and nitrogen oxide emissions are from human sources, such a coal burning power plants and industrial farms.

Mountain lakes provide homes for several federal Species of Concern—the Western Toad, Van Dyke Salamander, and Larch Mountain Salamander. Mountain lakes serve as prime habitat for amphibians, which are key components of Pacific Northwest ecosystems. They are both predators and prey, and act as environmental indicators due to their high sensitivity to contaminants and UV radiation. Amphibians are restricted by narrow geographic, elevation, and reproductive limits. In recent years, large numbers of native frogs and toads have declined in western North America. Much of this decline is due to habitat loss and fragmentation and the spread of invasive species, but causes are unknown for many other species found in pristine environments like NPS mountain lakes. Amphibians, zooplankton, and insects in NCCN parks may all be affected by contaminants, disease, nonnative fish, and climate change.

"The average person just thinks of a lake as a bathtub filled up with water, [but] it's a pretty complex world unto itself," Fradkin said.

## *Monitoring Strategy*

Scientists have studied NCCN mountain lakes for more than two decades, characterizing physical, chemical, and biological attributes of specific lakes and compiling park-wide inventories. Research has also focused on effects of air pollutants, recreational use, nonnative fish stocking, and potential amphibian population declines. The mountain lakes monitoring protocol is the first effort to monitor NCCN mountain lakes on a network-wide scale. The NPS developed the mountain lakes monitoring protocol in cooperation with the United States Geological Survey (USGS) Biological Resources Division. NPS scientists also work with the Washington State Department of Ecology, the U.S. Forest Service, and additional professors and researchers to increase monitoring capabilities and to compare data, said North Cascades park lead and mountain lakes principal investigator Reed Glesne. These other organizations supplement the efforts of the NPS by sampling additional variables, such as levels of pesticides and heavy metals in fish and amphibians.

NCCN mountain lakes are as unique as fingerprints, each with a different shape, surface area, depth, and temperature. Their wide range of aspect, terrain, bedrock, and vegetation is determined by the processes that shaped the surrounding lake basin and the lake itself. There are more than 1,500 lakes in the three large parks of the NCCN.

The NCCN currently monitors 20 mountain lakes annually: six at North Cascades, six at Mount Rainier, and eight at Olympic. None of the lakes selected by the NPS are exactly alike, but all are similar, thanks to the constraints of the protocol. This makes it possible to compare the lakes to each other, and to apply statistical inferences from the 20-lake sample set to the other 163 NCCN lakes that fall within these criteria. Although the number of lakes sampled is small, even reaching this number in a field season is challenging. The 20 lakes are "watch dogs" that will alert scientists to untoward changes in this otherwise "presumed pristine" environment.

An unnamed glacial lake in the North Unit of North Cascades National Park Complex Viewed from a helicopter. NPS/NOCA

The NPS selected its sample set of mountain lakes based on their elevation, size, accessibility, and surrounding vegetation. The sampled lakes are accessible by foot, at least 4,000 feet (1,219.2 m) above sea level, between 0.4 and 6 hectares in size, and more than 8.2 feet (2.5 m) deep. The sampled lakes also do not include lakes directly influenced by glaciers or those with large numbers of non-native fish. The elevation criteria place most sample lakes in the subalpine zone. Most subalpine lake basins are surrounded by sparse vegetation: patches of trees, meadows, talus slopes, and late-season snowfields.

Subalpine lakes are relatively cold, meaning they have high dissolved oxygen levels, and oligotrophic, meaning they have low levels of nutrients, such as phosphorous and nitrogen. Many of these lakes also have relatively neutral pH and low levels of dissolved solids. Water chemistry varies greatly between lakes depending on elevation, geographic setting, and the bedrock geology of the lake basin. A lake's elevation, topography and the direction it faces (its aspect) greatly influence its biological productivity and the length of time it remains frozen each year. South-facing lakes at lower elevations have more trees in their drainage and will have longer ice-free periods, whereas higher elevation lakes in narrow, north-facing drainages will have fewer trees and will remain ice-free fewer than two months. Lake basins with forested slopes will have higher amounts of woody debris, which creates shoreline habitat for insects and amphibians as well as contributing organic matter to the lake water. The longer a lake remains ice-free, the greater the biological activity that can take place in the lake during a summer season.

## *Data Collection*

Monitoring using the current protocol began at Mount Rainier in 2004, at Olympic in 2005, and at North Cascades in 2009. Every August and September, field crews take advantage of the brief window when mountain lakes thaw to conduct sampling. Sampling trips take between three and five days depending on a lake's accessibility and how researchers travel, said Mount Rainier biologist and mountain lakes principal lead Barbara Samora. Crews at Mount Rainier and Olympic hike to target lakes, carrying sampling gear on their backs.

Although all target lakes are accessible by foot, North Cascades has funding and permission to use helicopters to fly its crews to their sampling sites and pick them up a few days later. Occasionally North Cascades crews will hike into their sites, in which case they carry the lighter equipment typically used by crews at Olympic and Mount Rainier—replacing a 25-pound (11.3 kg) raft with a 2-pound (0.9 kg) inflatable, for example. With the smaller raft, "you're using two ping-pong paddles to get around, but it gets the job done," Glesne said. Instead of the large cooler carried in a helicopter, hiking researchers travel light by packing chunks of snow around water samples stuffed into insulated grocery bags to keep them cold during the trip back, Fradkin said. All monitoring methods attempt to have the least impact on the surrounding environment.

Crews monitor the health of the lake ecosystem by collecting samples of zooplankton, macroinvertebrates, amphibians, and fish in the lake. Crews also describe vegetation and any disturbance to shorelines. Beautiful days and settings are starkly contrasted with the challenges of sudden storms, drenching rains, and collapsing tents. By the end of September, nighttime temperatures drop to below freezing, and crews sometimes have to heat water to thaw out their frozen wading gear, Glesne said.

Crews also measure water clarity, water chemistry, lake temperature and ice phenology—when a lake's ice melts and when its surface waters freeze again. The duration of ice cover is a key indicator of climate change, and it greatly affects the life cycles of aquatic organisms in these ecosystems.

Water temperature and ice phenology are determined by deploying automatic data loggers that record air and lake water temperatures every hour, year round. Changing temperatures affect behavior of lake inhabitants and point toward potential climate change trends. For water temperature, park staff have deployed a buoy in the deepest part of the lake. The buoy is anchored to the bottom of the lake, with one temperature logger at the bottom, one in the middle of the water column, and one just below the surface. The surface logger is used to determine when ice cover forms and melts, and also gives scientists a more accurate picture of when lake waters mix and if and when the lake stratifies, separating into different layers based on temperature and density during the summer. From a small boat near the buoy, park staff will also lower a datasonde, an instrument that takes continuous measurements of dissolved oxygen, temperature, and pH during their site visit. Finally, a measurement of water clarity is taken when staff record the depth at which a black and white Secchi disk disappears from view as it is lowered into the lake.

### *Current Trends*

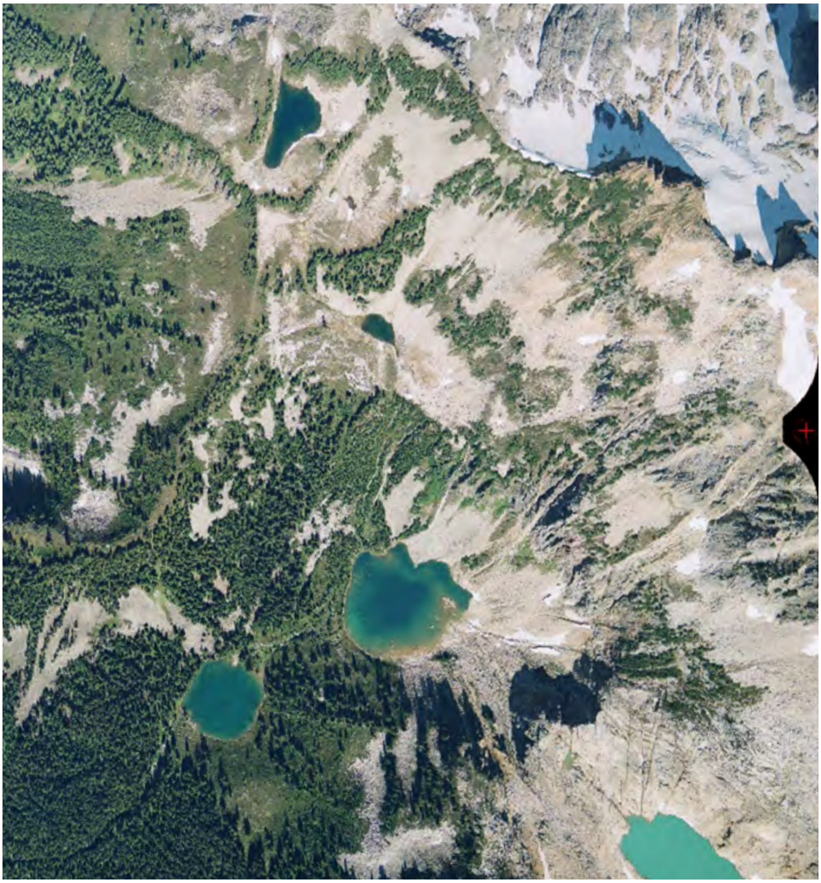
As with other Vital Signs monitoring protocols, studying mountain lakes is a long-term monitoring program. With only a few years of data so far, it is too early to identify any trends. It usually takes a minimum of five years to start detecting trends, sometimes as long as 10 or 15 years, Glesne said.

However, scientists have noticed some patterns regarding the timing of when lakes thaw and freeze over. In 2010, a year with a high snow pack and cool spring conditions, lakes thawed later than usual, whereas in 2009, they thawed early. Most study lakes thaw in mid-July and freeze again in early November. Some deeper, higher elevation lakes with North or East aspects occasionally thaw as late as early October and freeze again in November. These temperature changes affect the life cycles of organisms in mountain lake ecosystems. In June 2009, fish began spawning while snow still covered the ground, but in 2010, they waited much later to spawn.

“Five years from now, potential trends in water temperature changes may begin to emerge,” Fradkin said, but since this program is more geared toward long-term monitoring, scientists will be able to speak to trends more strongly after 15 years.

Sampling is also valuable because it documents consequences of human actions. It is important for the NPS to work with other agencies and acknowledge that climate change is occurring, Samora said.

“I think you have to make the point to the public that increasing your carbon footprint has an effect on these remote and supposedly pristine places,” Samora said. “It’s kind of sad that the most protected places that we know of in our country aren’t really protected from climate change and atmospheric contaminants.”



Blum Lakes, located in the North Unit of North Cascades National Park Complex, WA. NPS/NOCA

In the past, data collected by the NPS at remote locations in NCCN parks has demonstrated the impacts of these anthropogenic stressors. The political sway of these findings has influenced the locations and operations of power plants and other industrial sites.

"The Park Service can't just call up the power plant and say 'hey, stop doing that,' but it can call up Congress and say 'if this is happening in pristine areas, how about others?'" Fradkin said. This influence is indirect, but still compelling, and it does influence policies and regulations.

"These lakes are some of the crown jewels that we have in National Parks," Fradkin said. "They're aesthetically beautiful, and they're a vital part of these mountain ecosystems."

# *Contact Information*

| | | |
|---|---|---|
| *Science Learning Network* | | |
| Dr. Jerry Freilich, OLYM | jerry_freilich@nps.gov | 360-565-3082 |
| Michael Liang, NOCA | michael_liang@nps.gov | 360-854-7305 |
| Dean Butterworth, OLYM | dean_butterworth@nps.gov | 360-565-3146 |
| *Inventory and Monitoring* | | |
| Dr. Mark Huff, MORA | mark_huff@nps.gov | 253-306-4473 |
| *Landscape Dynamics* | | |
| Dr. Catharine Thompson, OLYM | catharine_thompson@nps.gov | 360-565-2979 |
| Natalya Antonova, NOCA | natalya_antonova@nps.gov | 360 854-7312 |
| *Climate* | | |
| Bill Baccus, OLYM | bill_baccus@nps.gov | 360-565-3061 |
| Rebecca Lofgren, MORA | rebecca_a_lofgren@nps.gov | 360-569-6752 |
| Mike Larrabee, NOCA | mike_larrabee@nps.gov | 360-854-7333 |
| *Mountain Lakes* | | |
| Dr. Steven Fradkin, OLYM | steven_fradkin@nps.gov | 360-928-9612 |
| Reed Glesne, NOCA | reed_glesne@nps.gov | 360-854-7315 |
| Barbara Samora, MORA | barbara_samora@nps.gov | 360-569-2211 x3372 |
| *Glaciers* | | |
| Dr. Jon Riedel, NOCA | jon_riedel@nps.gov | 360-854-7330 |
| *Landbirds* | | |
| Dr. Patti Happe, OLYM | patti_happe@nps.gov | 360-565-3065 |
| Robert Kuntz, NOCA | robert_kuntz@nps.gov | 360-854-7320 |
| *Intertidal* | | |
| Dr. Steven Fradkin, OLYM | steven_fradkin@nps.gov | 360-928-9612 |
| *Forest Vegetation* | | |
| Dr. Steve Acker, OLYM | steve_acker@nps.gov | 360-565-3073 |
| Mignonne Bivin, NOCA | mignonne_bivin@nps.gov | 360-854-7335 |
| Lou Whiteaker, MORA | lou_whiteaker@nps.gov | 360-569-2211 x3387 |
| *Fish Populations* | | |
| Sam Brenkman, OLYM | sam_brenkman@nps.gov | 360-565-3081 |
| *Elk* | | |
| Dr. Patti Happe, OLYM | patti_happe@nps.gov | 360-565-3065 |

**MOUNTAIN LAKES**

Glesne, R.S., S. C. Fradkin, B.A. Samora, R.E. Holmes and B.A. Christoe. May 2010 NCCN Draft Mountain Lakes Protocol: 2011. Protocol for long term monitoring of mountain lakes in the North Coast and Cascades Network of National Parks. Natural Resource Report NPS/NCCN/NRR—2011/000. National Park Service, Fort Collins, CO.

National Park Service Inventory & Monitoring Program. Mountain Lakes Monitoring. *http://science.nature.nps.gov/im/units/nccn/vs/mountain_lakes/mountain_lakes.cfm*

National Park Service. 2010 Resource Brief Annual. *http://nwparkscience.org/*

**GLACIERS**

Granshaw, F.D. 2001. Glacier Change in the North Cascades National Park Complex, Washington State USA, 1958-1998. Master's Thesis, Portland State University. Portland, OR.

GreenFacts.org. Scientific Facts on Water Resources. *http://www.greenfacts.org/en/water-resources/index.htm#2*

National Park Service. North Cascades National Park Glacier Monitoring Program website. *http://www.nps.gov/noca/naturescience/glacial-mass-balance1.htm*

Riedel, J. L., R. A. Burrows, and J. M. Wenger. 2008. Long term monitoring of small glaciers at North Cascades National Park: A prototype park model for the North Coast and Cascades Network, Natural Resource Report NPS/NCCN/NRR—2008/066. National Park Service, Fort Collins, CO.

Riedel, J. L., J. M. Wenger, and N. D. Bowerman. 2010. Long term monitoring of glaciers at Mount Rainier National Park: Narrative and standard operating procedures version 1.0. Natural Resource Report NPS/NCCN/NRR—2010/175. National Park Service, Fort Collins, CO.

**LANDBIRDS**

Institute for Bird Populations. *http://www.birdpop.org/*

National Park Service Inventory and Monitoring program. North Coast and Cascades Network landbirds information. *http://science.nature.nps.gov/im/units/nccn/vs/landbirds/landbirds.cfm*

Point Reyes Bird Observatory. Oregon and Washington Partners In Flight. Bird Population information. *http://cain.ice.ucdavis.edu/prbo/orwapif/*

Siegel, R. B., R. L. Wilkerson, and R. C. Kuntz II. 2008. North Coast and Cascades Network landbird monitoring report for the 2007 field season. Natural Resource Technical Report NPS/NCCN/NRTR—2008/114. National Park Service, Fort Collins, CO.

Siegel, R. B., R. L. Wilkerson, and R. C. Kuntz II. 2009. Landbird monitoring in the North Coast and Cascades Network. Report for the 2006 pilot field season. Natural Resource Technical Report NPS/NCCN/NRTR—2009/168. National Park Service, Fort Collins, CO.

Siegel, R.B., Wilkerson, R.L., Jenkins, K.J., Kuntz II, R.C., Boetsch, J.R., Schaberl, J.P., and Happe, P.J., 2007, Landbird monitoring protocol for national parks in the North Coast and Cascades Network: U.S. Geological Survey Techniques and Methods 2–A6, 200 p.

United States Geological Survey. Breeding Bird Survey. *http://www.pwrc.usgs.gov/BBS/*

Wilkerson, R. L., R. B. Siegel, and R. C. Kuntz II. 2009. North Coast and Cascades Network landbird monitoring: Report for the 2008 field season. Natural Resource Technical Report NPS/NCCN/NRTR—2009/222. National Park Service, Fort Collins, CO.